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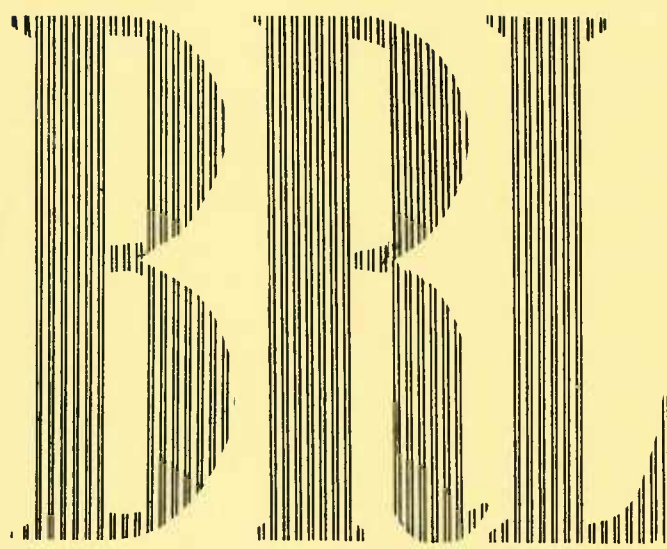Approved for public release; distribution is unlimited.

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MEMORANDUM REPORT No. 956

DECEMBER 1955

Aerodynamic Characteristics Of The 175MM T203 Shell And The 175MM Square Base Shell With Fuze M51A5

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B. HULL

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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A B E R D E E N   P R O V I N G   G R O U N D ,   M A R Y L A N D

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BGKarpov/KSkegas/BHull/sdb
Aberdeen Proving Ground, Maryland
December 1955

AERODYNAMIC CHARACTERISTICS OF THE 175MM T203 SHELL AND THE 175MM SQUARE BASE SHELL WITH FUZE M51A5

ABSTRACT

This report presents the aerodynamic characteristics of two shell designed for the 175mm gun. These were determined by firing 90mm diameter scaled models in the Transonic Range of the Exterior Ballistics Laboratory.

TABLE OF SYMBOLS

A	Axial moment of inertia
B	Transverse moment of inertia
d	Diameter
K_D	Drag coefficient
K_{DO}	Zero yaw drag coefficient
$K_{D_{\delta^2}}$	Yaw drag coefficient
K_H	Damping moment coefficient
K_L	Lift force coefficient
K_M	Overturning moment coefficient
K_N	Normal force coefficient
M	Mach number
m	Mass (weight)
n	Twist of gun
s	Gyroscopic stability factor
$\bar{s}$	Dynamic stability factor
$\lambda_{1,2}$	Damping rates of epicyclic yaw arms
$\overline{\delta^2}$	Mean squared yaw
ρ	Density of air
S_L	Swerve associated with the lift force
$K_{1,2}$	Magnitude of epicyclic yaw arms
ϵ_i	Standard error in a coefficient or in a least squares fit
CP_N	Normal force center of pressure
c.m.	Center of mass
σ	$\sqrt{1 - \dfrac{1}{s}}$

INTRODUCTION

For the past few years the Ordnance Corps has been concerned with the development of a high capacity, low drag, high explosive shell for a new series of weapons: the 110mm and the 156mm howitzers and the 175mm gun. The actual development of this shell was done in the 110mm size because of cost considerations and availability of the 110mm howitzer tubes. The story of this development will be told elsewhere.

The shell for the 156mm howitzer and the 175mm gun were to be scaled-up versions of the 110mm shell. However, exact scaling could not be accomplished because the same M51A5 fuze was to be used for all three sizes. Therefore, the ogival heads of the larger shell had to be slightly different. The adjustment was made by rotating the arc of the circle defining the ogive, about the point of junction of the head and the body. This slightly increased the bluntness of the head and should be reflected in about 3 - 4 percent higher drag.

The drag function for the 110mm shell was determined only up to $M = 1.6$. This should suffice for the 156mm shell. However, for the 175mm, the muzzle velocity must be considerably higher; hence the drag function had to be extended to higher Mach numbers.

Unfortunately, simple extrapolation of the 110mm drag curve appeared inadequate. It was tried however, and on this basis it was found that the muzzle velocity necessary to attain the maximum specified range for the 175mm gun is 2950 fps. To obtain this high velocity, the original chamber volume of the 175mm gun would have to be enlarged. In order to modify the chamber volume by the least possible amount, a more precise drag curve, extending to higher Mach numbers, was desirable. Neither the 175mm gun nor the shell were yet available for necessary firings. Therefore, Firestone Tire and Rubber Company, an Ordnance contractor on this project, designed and manufactured scaled models of the 175mm shell T203 in 90mm size, see Figure 1.

Firestone also manufactured models with a square base. These were
of the same overall length as the T203 shell but instead of a one caliber
long boattail, the head was lengthened by one caliber, Figure 2. The
purpose of this model was to explore the possibility of designing a square
based shell with the same drag as the boattailed shell. From certain con-
siderations, the square based shell is more attractive than the boattailed
one.

Both of these models were fired in the Transonic Range of the Exterior
Ballistics Laboratory. They were fired from the 90mm M3 gun with a twist
of rifling of 1:32. Hence, in order to assure their gyroscopic stability,
when fired from this relatively low twist gun, (the twist of the 175mm
gun is 1:20), they were designed with bi-metal construction so as to
increase their A^2/B ratio.

TEST PROGRAM

Eighteen T203 models and sixteen square based models, which, on the
graphs of data, for lack of a better name, are called T203 square base,
were fired in the Transonic Range[1] between Mach numbers 1.1 and 2.6.
Their physical characteristics are given in the Appendix.

In order to study aerodynamic properties, other than drag, it is
essential to have adequate yaw. Because the natural yaws of these shell
proved to be too small, yaw was deliberately induced by a special muzzle
adapter. Some of the yaws were a bit too large: of the order of 8 - 9
degrees.

EXPERIMENTAL RESULTS

Drag Force and Yaw Drag Coefficients

The drag force coefficient K_D, is obtained from a least squares fit
of a cubic equation to time-position data[2]. Since drag is a function of
both Mach number and yaw, it is desirable to separate the effects of these
two. Assuming that drag is a linear function of mean squared yaw, K_D was
reduced to zero yaw by the relationship $K_D = K_{DO} + K_{D_\delta 2} \overline{\delta^2}$. It was found

that for both types of projectiles, over the range of Mach numbers tested, $K_{D_\delta}2$ was 0.0007 for yaws less than 75 square degrees and 0.0006 for yaws greater than 75 square degrees.

At supersonic velocities, a useful smoothing formula is $Q = \sqrt{1 + M^2 K_{DO}}$ = a + bM, where a and b are empirical constants. This Q function was fitted to the K_{DO} data between M = 1.30 and M = 2.6. The following constants were obtained:

$$a = .9582, \ b = .1106 \text{ for } 8^\circ \text{ B.T.},$$

$$a = .9580, \ b = .1160 \text{ for square base.}$$

K_{DO} is plotted versus Mach number in Figure 3. The drag of the square base shell is about 6 - 7% higher than that of the 8° B.T. For comparative purposes, data from firings of the 110mm T194 shell, with an 8° boattail and the M51A5 fuze are also plotted on this graph.

It is to be noted that the drag coefficients of the 110mm T194 shell are lower than those of the model of the T203 shell. As mentioned before, they should be lower by 3 - 4 percent because of the blunter head of the 175mm shell. Moreover, close scrutiny of the drawings of the 90mm model and the full scale shell showed some small geometrical differences. One difference was due to accentuated body undercut on the model between the front and the rear bourrelets; another, a plus tolerance at the base of the fuze which made the fuze slightly blunter. At most, these geometric differences between the model and the real shell, if both were made in accordance with their respective drawings, should increase the drag of the model by about 5%. However, tolerances on the model drawing were not given and the actual dimensions might be presumed to be maximum. Thus the drag coefficients of the models we fired might differ from the real shell by less than 5%, say by only 2 to 3 percent. Thus the total difference in drags between the 110mm T194 shell and the 90mm model should be of the order of 5 - 6 percent. Therefore, if we depress the model drag by, say, 5%, these drag coefficients should join smoothly the available data for the T194 shell. This has been done by the Computing Laboratory. The

drag curve for the 110mm T194 shell has been defined, at supersonic velocities, as 95% of our 90mm model firings curve. Relative to this drag curve, the form factor of the 175mm T203 shell should be 3 - 4 percent higher.

It is unfortunate, of course, that small geometric dissimilarities between the model and its prototype confuse the picture and make the drag determination of the real shell from its model firings somewhat indeterminate within a few percent. This uncertainty has to be resolved by firing the real shell which, in effect, defeats the principal purpose of the present experiments. Very accurately designed and manufactured models are essential parts of a test of this nature.

Overturning Moment and Normal Force Coefficients

The overturning moment coefficient, K_M, was obtained from the turning rates of the two arms of the characteristic epicyclic yawing motion of a spinning missile. In Figure 4, K_M is plotted versus Mach number for the two models. The data for the square base model are markedly lower than the 8° B.T., largely because of the difference in the centers of pressure of the two shapes. The difference in c.g. of .09 calibers is relatively small.

The normal force coefficient, K_N, was determined from the analysis of the swerving motion. The data are plotted for those rounds that had a swerving arm, $S_L, \geq .035$ ft., (Figure 5). At lower Mach numbers, K_N of the 8° B.T. is lower than that of the square base as is expected. At the higher Mach numbers, the two are in substantial agreement within the scatter of the data.

In Figure 6, are plotted the normal force centers of pressure for the two types of models. These plots show the well known characteristic that as one approaches sonic velocity, the center of pressure for the boattailed configuration moves forward much more rapidly than that of the square based shape.

Magnus and Damping Moment Coefficients

The Magnus moment coefficient, K_T, shows considerable scatter but appears to be fairly constant at a level of about - .06 for both the 8° B.T. model and the square base shell. In Figure 7, K_T is plotted versus Mach number.

The damping moment coefficient, K_H, is rather poorly determined and is plotted versus Mach number in Figure 8. The coefficient appears to be fairly constant over the range of velocities in the experiments. For the boattailed shell K_H is about 3; for the square based shell it appears to be slightly higher, which might be due to the difference in c.g.

The yaw damping rates, $\lambda_{1,2}$, are for the full scale 175mm shell, and were computed using pertinent aerodynamic data and the physical characteristics of the full scale shell. These were computed for 1:20 twist. (λ_1 and λ_2 are plotted versus Mach number in Figure 9 and Figure 10). There is very little difference between the 8° B.T. and the square base shell; both are dynamically stable configurations over the range of Mach numbers covered by these tests.

Recent Firings of Full Scale 175mm T203 Shell

Recently a small group of the T203 shell were range-fired for accuracy. The firings were analysed on the basis of the drag curve of the 110mm T194 shell obtained as described above. The inferred form factor for the T203 shell was found to be 1.05; that is, the drag of the T203 shell is 5% higher than that of the T194 shell. It was expected to be only 3 - 4 percent higher. This suggests that we have overcorrected the model drag by about 2%. Or, put in another way, the apparent geometrical dissimilarities between the model and the real shell did not contribute as much to drag disparities as we have estimated.

There is another possibility. It is known, judging by certain physical measurements which have been made on a group of the T203 shell, of which the fired sample formed a part, that these shell were not well made. Thus there is a possibility that the fired shell were dynamically unbalanced.

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Such an eccentric shell will launch poorly, with trim at non-zero yaw and will have slightly higher drag. A yaw of about two degrees would suffice to account for the expected and the observed differences in drag of two to three percent. This matter is being investigated further.

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APPENDIX

A sketch of the 90mm model of the 175mm shell is given in Figure 1. Figure 2 presents the physical data for the square base model. The aerodynamic data for the two models is presented in Tables 1 and 2.

Mean squared yaw, $\overline{\delta^2}$, is in square degrees; $\lambda_{1,2} \times 10^3$ are given in units of $(\frac{1}{ft})$; $K_{1,2}$ are in radians; S_L is in feet. s is the gyroscopic stability factor; a condition for stability is that $s \geqq 1$. The dynamic stability factor is $\overline{s}$; the condition for dynamic stability is $0 < \overline{s} < 2$. Both the 8° B.T. and the square base models had gyroscopic and dynamic stability.

The average standard error of the mean squared yaw is:

ϵ_y of 8° B.T. = .003 radians

ϵ_y of square base = .003 radians

The average standard error in swerve is:

ϵ_s of 8° B.T. = .015 ft.

ϵ_s of square base = .017 ft.

The average standard errors, in percent, of the various aerodynamic coefficients are approximately as follows:

8° B.T.	Square base
ϵ_{K_N} = 12%	ϵ_{K_N} = 8%
ϵ_{K_M} = 1.5%	ϵ_{K_M} = 0.9%
ϵ_{K_T} = 39%	ϵ_{K_T} = 39%
ϵ_{K_H} = 24%	ϵ_{K_H} = 15%

Shadowgraphs of the 8° B.T. and square base shell are shown in Figures 11 and 12. A photograph of the M3, 90mm gun with muzzle adaptor for inducing yaw is shown in Figure 13.

TABLE 1

Aerodynamic Data of the 8° B. T. 90mm Model

Round No.	M	$\overline{\delta^2}$ (deg)²	K_D	K_N	K_M	K_H	K_T	$\lambda_1 \times 10^3$ 1/ft.	$\lambda_2 \times 10^3$ 1/ft.	s *	$\overline{s}$	S_L feet	$\|K_1\|$ radians	$\|K_2\|$ radians	s **
2978	1.142	4.98	.1376	.70	1.89	3.06	-.05	1.77	-.30	1.09	.49	.067	.065	.036	1.48
2979	1.148	11.64	.1404	.64	1.86	3.08	-.17	.83	.61	1.10	.94	.075	.033	.047	
2975	1.291	.98	.1259												
2976	1.303	1.26	.1255												1.55
2993	1.412	.36	.1206												
2992	1.420	1.72	.1214												
2962	1.663	20.66	.1271	1.30	1.69	3.13	-.11	.98	.54	1.18	.87	.035	.044	.063	1.65
2961	1.688	1.91	.1114												
2973	1.861	.98	.1038												
2974	1.869	1.54	.1050												
2963	2.076	.59	.0963												
2960	2.092	2.81	.0945		1.59	3.68	-.07	1.42	.27	1.21	.70		.008	.028	1.75
2970	2.218	1.26	.0933												
2972	2.232	.93	.0914												
2966	2.381	8.80	.0939		1.51	3.60	-.10	1.23	.31	1.25	.72		.029	.040	
2965	2.389	28.46	.1067	1.55	1.51	2.51	-.08	.68	.66	1.25	.99	.039	.065	.063	1.85
2991	2.562	55.00	.1195	1.48	1.48	2.50	-.09	.64	.64	1.33	1.00	.073	.091	.097	
2969	2.602	32.30	.1032		1.48	2.76	-.06	.94	.31	1.29	.75		.067	.073	1.90
2967	2.630	80.70	.1384												

*   Twist of rifling 1:32
** s computed for real 175mm shell with a 1:20 twist.

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TABLE 2

Aerodynamic Data of the Square Base 90mm Model

Round No.	M	$\overline{\delta^2}$ (deg)^2	K_D	K_N	K_M	K_H	K_T	$\lambda_1 \times 10^3$ 1/ft.	$\lambda_2 \times 10^3$ 1/ft.	s	$\bar{s}$	S_L feet	$|K_1|$ radians	$|K_2|$ radians	s **
3171	.965	17.25	.1116		1.16	4.26	-.08	1.70	-.17	1.10	.57		.048	.056	2.42
3170	1.203	61.97	.1794	1.05	1.18	3.68	-.07	1.45	.24	1.10	.71	.061	.060	.012	2.37
3174	1.225	.32	.1377												
3169	1.373	96.55	.1898	1.23	1.20	2.96	-.07	1.00	.64	1.09	.91	.071	.119	.012	
*3176	1.393	3.54	.1325	1.22	1.16	2.92		.83	.31	1.80	.68	.045	.020	.069	2.31
3168	1.614	72.31	.1697	1.28	1.21	3.82	-.07	1.60	.34	1.07	.77	.069	.074	.125	
*3181	1.736	2.21	.1154					2.18	.03	1.83			.014	.020	2.31
3162	1.810	37.99	.1404	1.23	1.18	4.30	-.08	1.80	.15	1.07	.72	.051	.040	.097	2.35
*3177	1.875	3.94	.1119		1.15	4.37	-.09	.99	.42	1.84	.74		.017	.029	
3161	2.107	79.66	.1455	1.42	1.17	3.11	-.03	1.30	.32	1.08e	.78	.087	.082	.013	
*3178	2.121	.94	.1033		1.17	3.02		1.36	.26				.010	.014	
3164	2.229	42.97	.1262	1.37	1.15	2.54	-.02	1.05	.36	1.08	.83	.066	.052	.103	2.50
*3180	2.385	22.06	.1079		1.12	3.80	-.07	.92	.43	1.83	.75		.052	.062	2.51
3163	2.453	11.63	.0955		1.15					1.12	.57		.024	.050	
*3179	2.567	7.42	.0949		1.10	3.75	-.07	.93	.35	1.86	.69		.030	.039	
3167	2.604	6.76	.0913	1.47	1.11		-.06	1.61	.19	1.12	.72	.037	.016	.073	2.52

* Twist of rifling 1:25

** s computed for real 175mm shell with a 1:20 twist.

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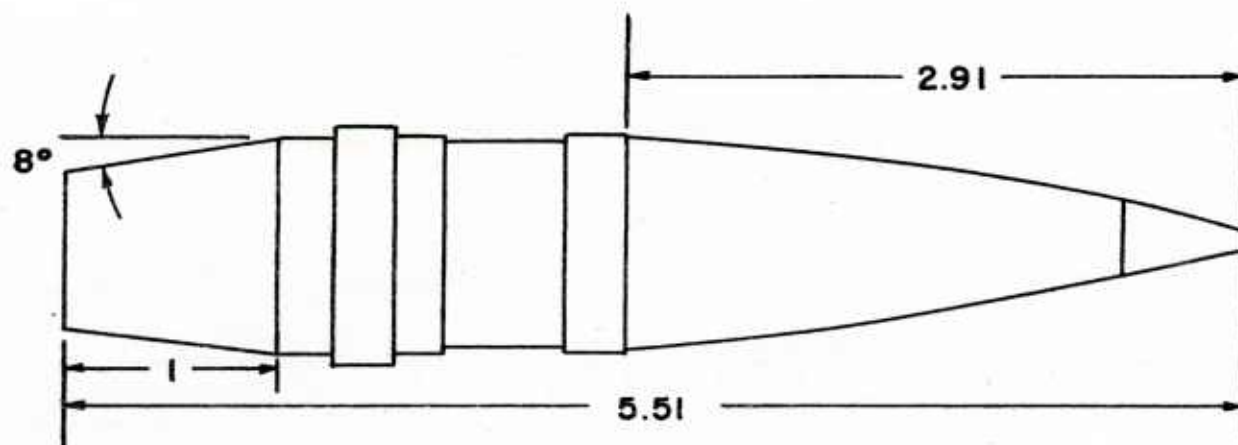
90mm BAL SLUG
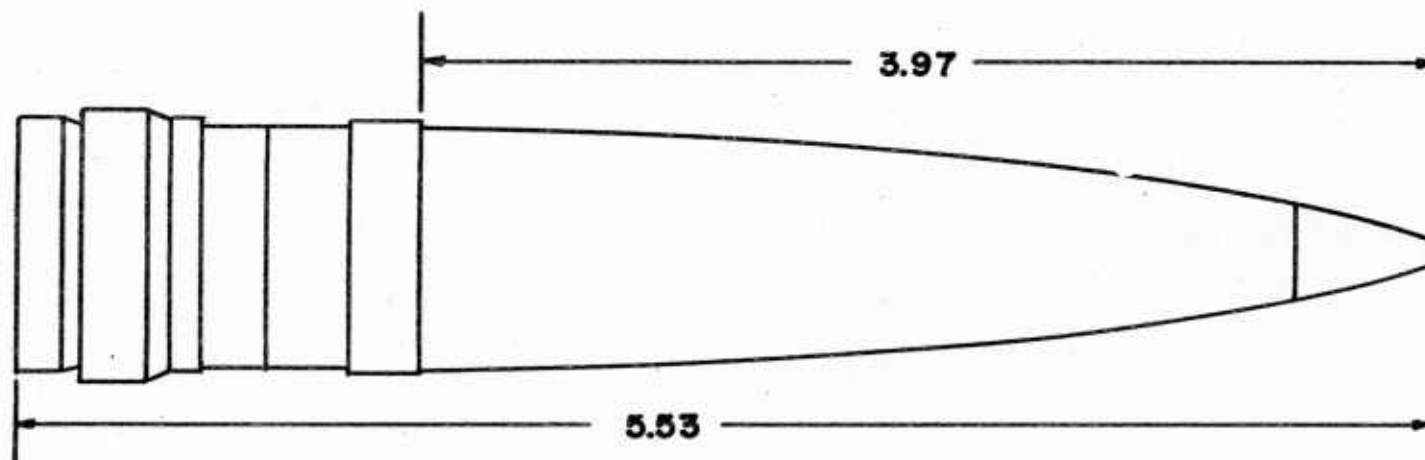MODEL OF 175mm SHELL

ALL DIMENSIONS ARE IN CALIBERS

WT. 21.82 lbs.
A   34.76 lbs.-inch^2
B   246.9 lbs.-inch^2
C.G. 1.940 CAL. FROM BASE

FIG. I

3.97

5.53

90 mm BAL SLUG

WT. 21.21 lbs.

A 30.71 lbs.-inch²

B 302.1 lbs.-inch²

CG 1.853 CAL. FROM BASE

ALL DIMENSIONS ARE IN CALIBERS

FIG. 2

ZERO-YAW DRAG COEFFICIENT
vs.
MACH NUMBER

FUSE M51A5
● 175 mm T-203, 8° B.T.
⊙ 175 mm T-203, SQ. BASE
△ 110 mm T-194, 8° B.T.

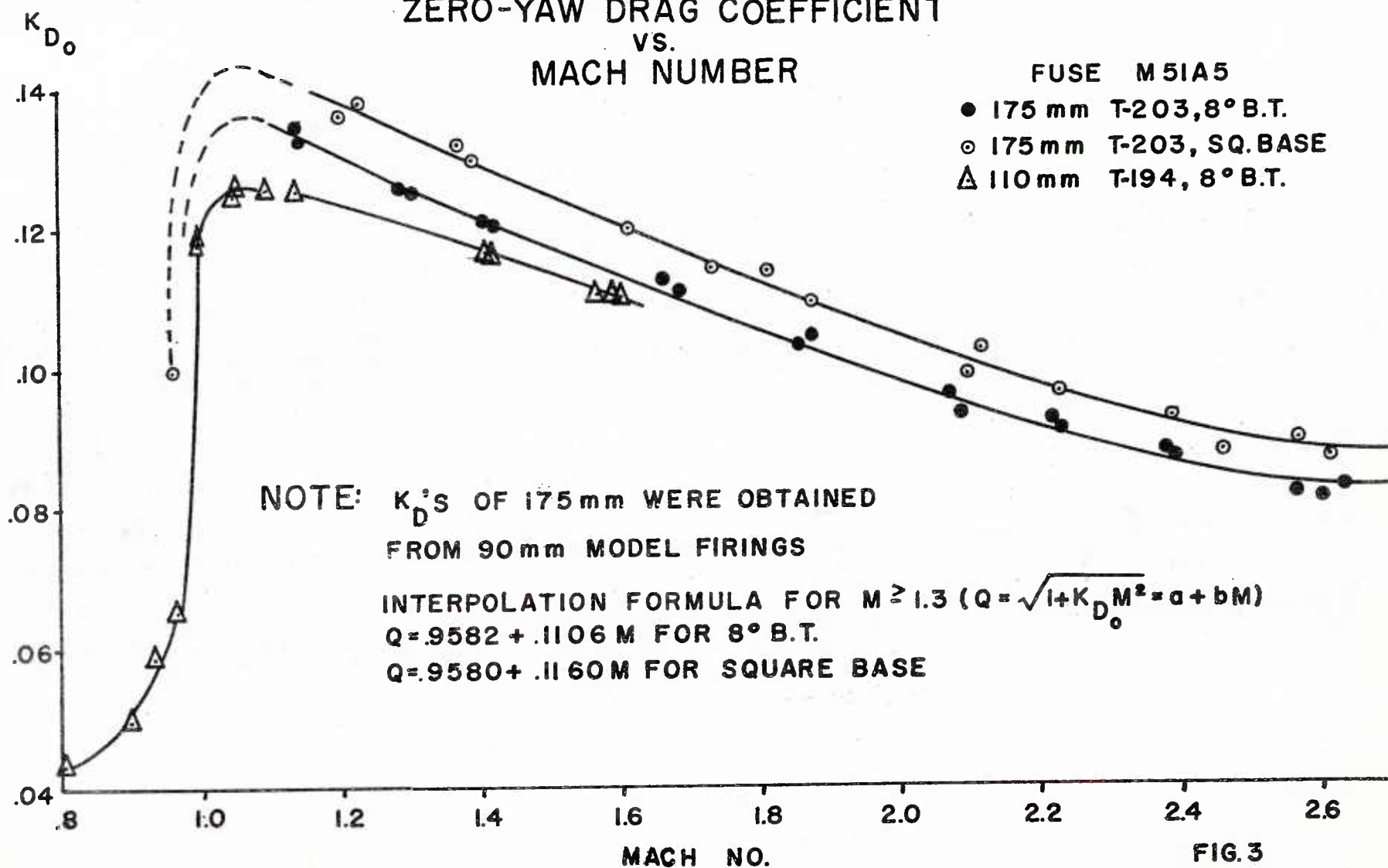NOTE: K_D'S OF 175mm WERE OBTAINED
FROM 90mm MODEL FIRINGS

INTERPOLATION FORMULA FOR $M \geq 1.3$ $(Q = \sqrt{1 + K_{D_o} M^2} = a + bM)$
$Q = .9582 + .1106 M$ FOR 8° B.T.
$Q = .9580 + .1160 M$ FOR SQUARE BASE

MACH NO.

FIG. 3

OVERTURNING MOMENT COEFFICIENT
VS
MACH NUMBER

● 175 mm T-203, 8° B.T.
⊙ 175 mm T-203, SQ. BASE
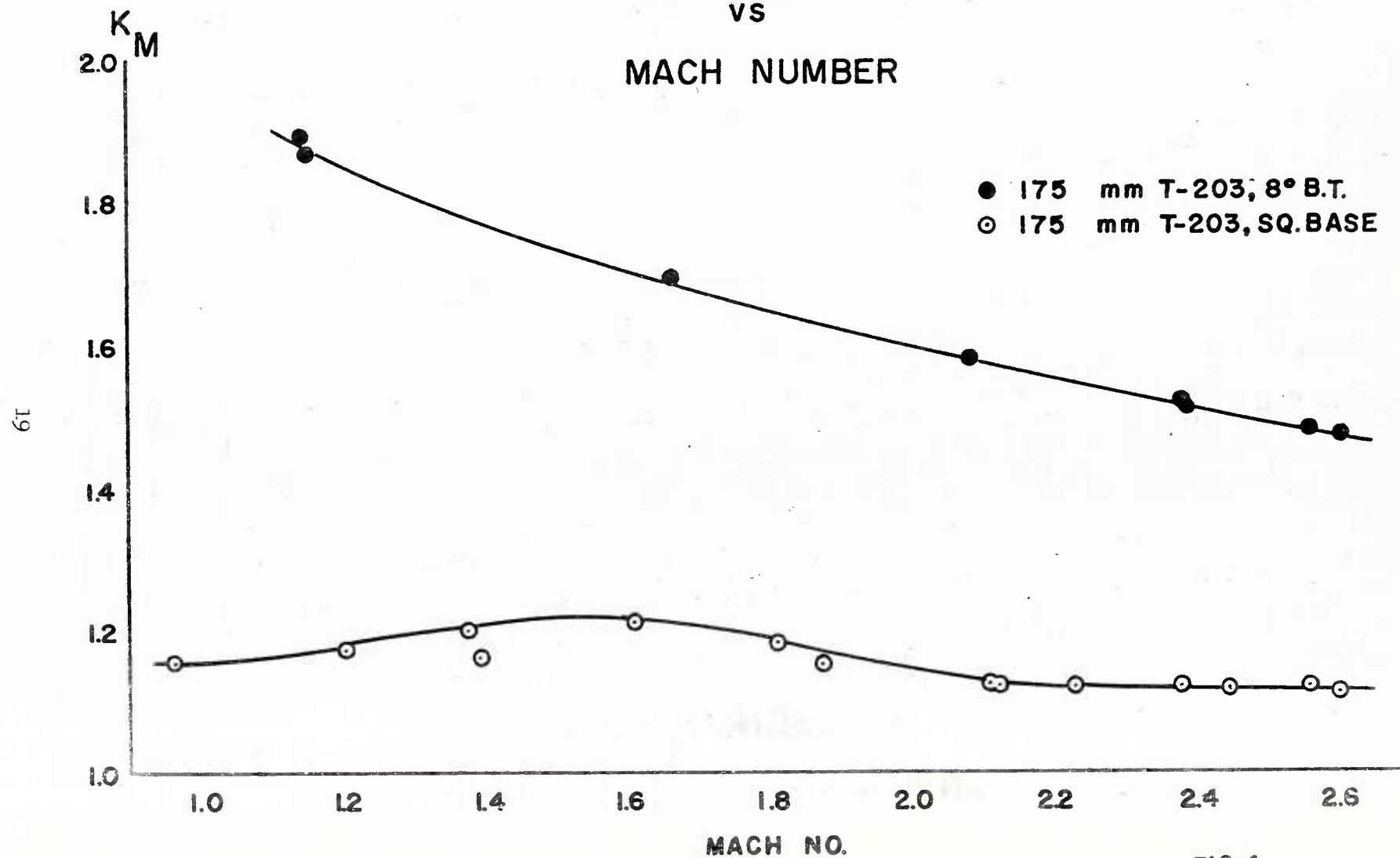
MACH NO.

FIG. 4

NORMAL FORCE COEFFICIENT
vs.
MACH NUMBER

● 175 mm   T-203, 8° B.T.
⊙ 175 mm   T-203, SQ.BASE

MACH NO.

FIG. 5

NORMAL FORCE CENTER OF PRESSURE
VS
MACH NUMBER

CP$_N$

5

4

CALIBERS FROM BASE

3

2

1

0

21

● 175 mm T-203, 8° B.T.

⊙ 175mm T-203, SQ. BASE

1.0   1.2   1.4   1.6   1.8   2.0   2.2   2.4   2.6
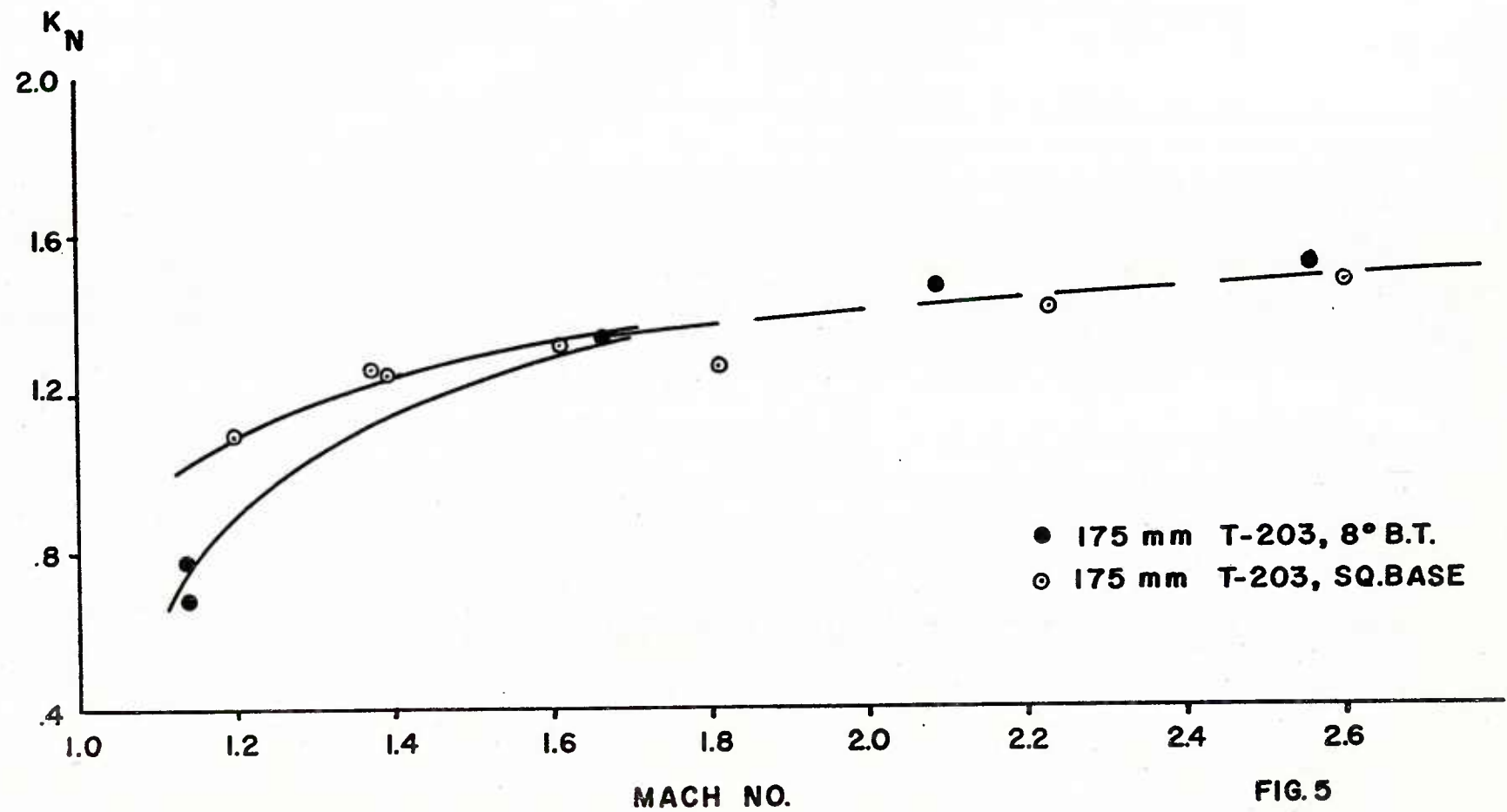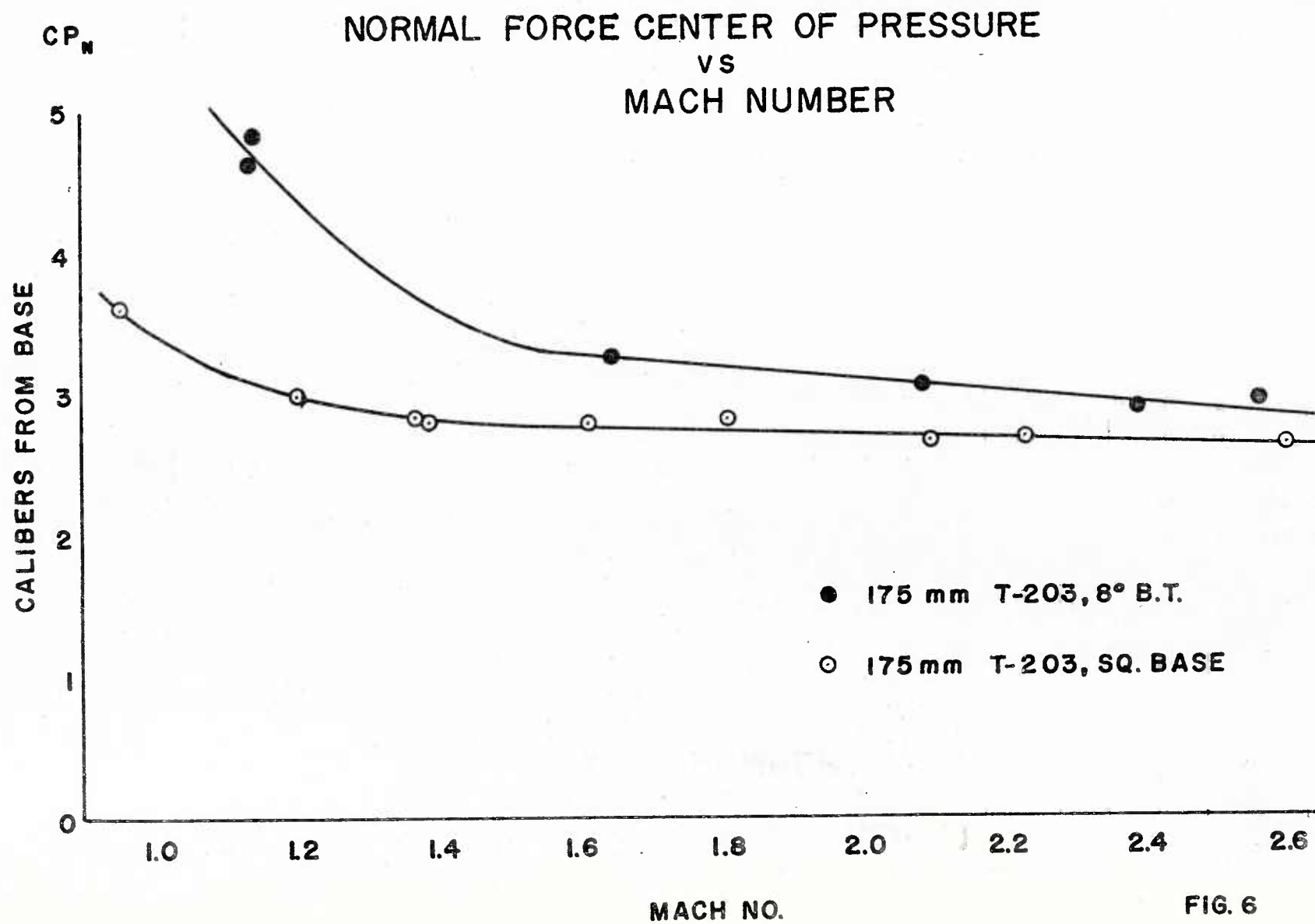
MACH NO.   FIG. 6

MAGNUS MOMENT COEFFICIENT
vs
MACH NUMBER

FIG. 7

DAMPING MOMENT COEFFICIENT
vs
MACH NUMBER

● 175 mm T-203, 8° B.T.
⊙ 175 mm T-203, SQ. BASE

23
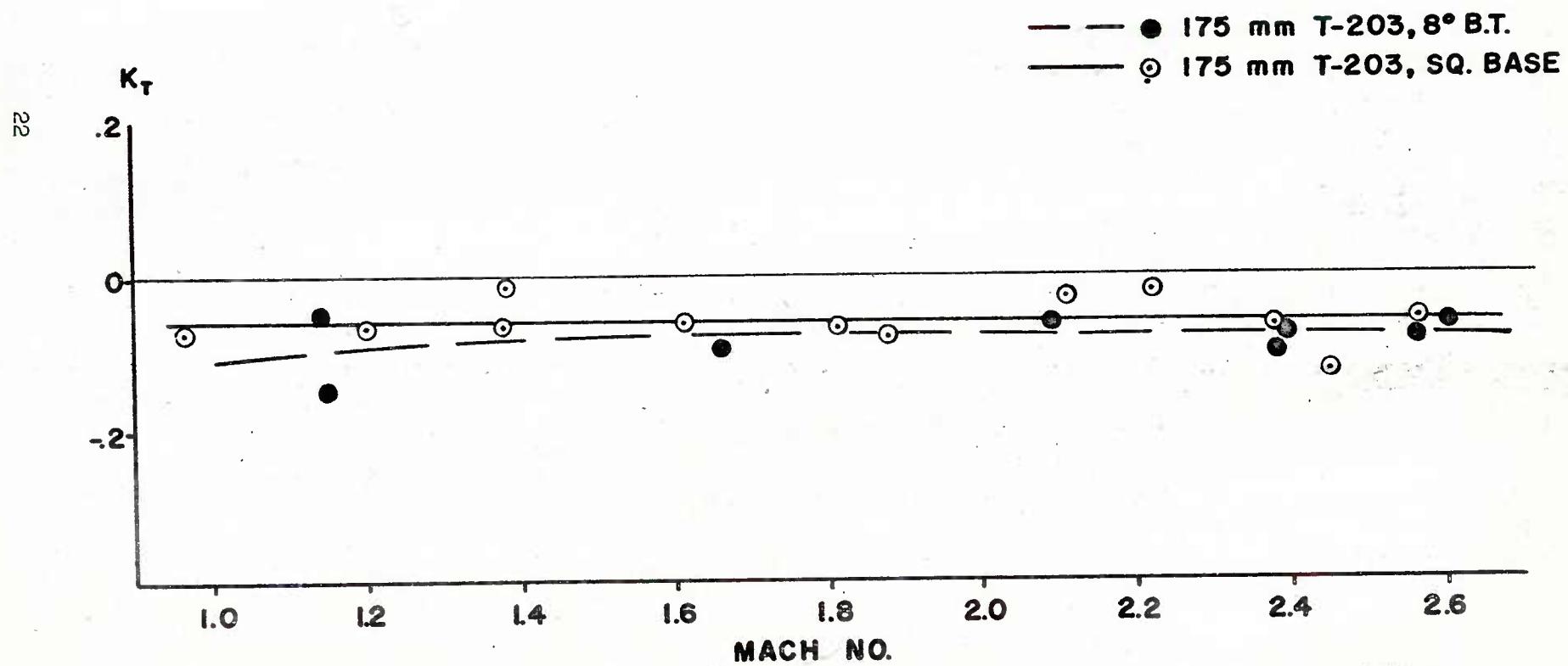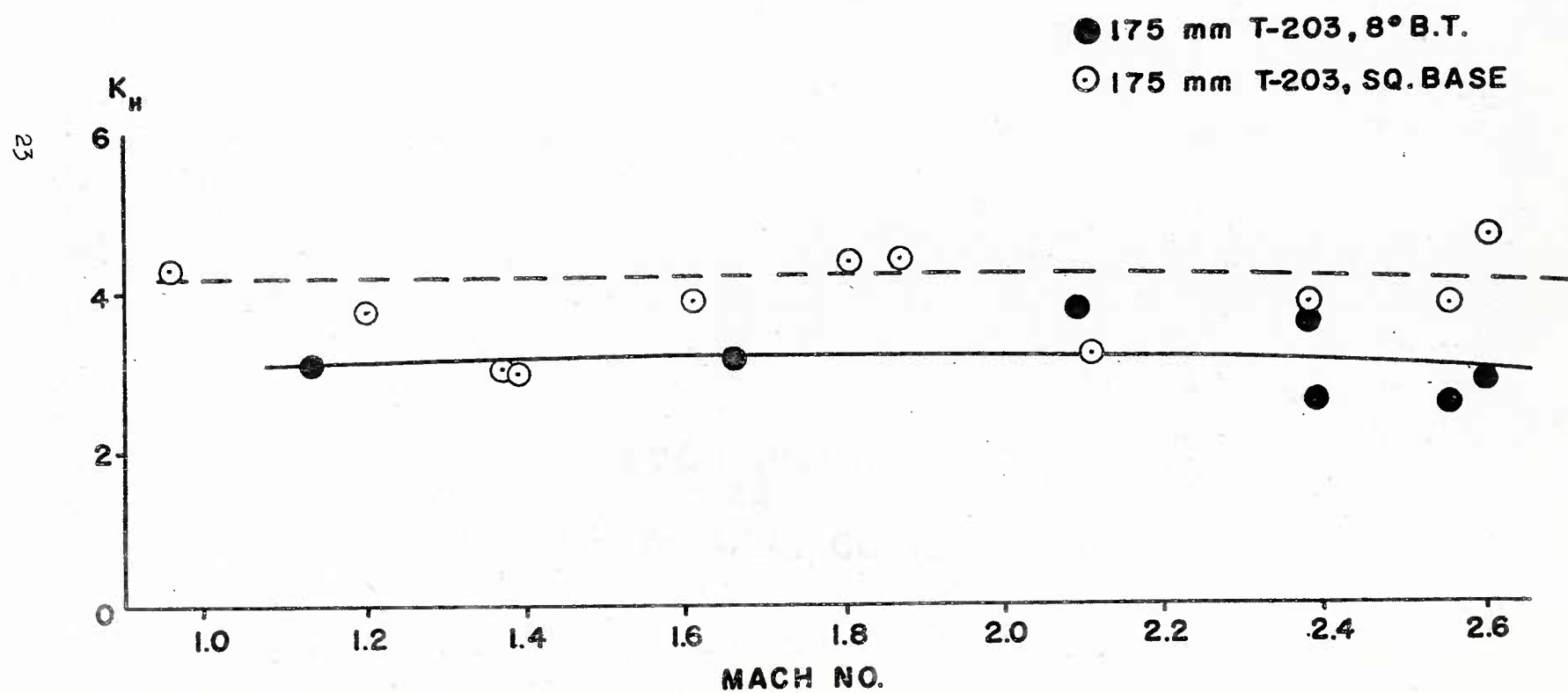
FIG. 8

NUTATIONAL YAW DAMPING RATE, $e^{-\lambda_1 z}$
VS
MACH NUMBER

FULL SCALE SHELL

FUSE M 51A5
———— 175 mm T-203, 8° B.T.
- - - - 175 mm T-203, SQ. BASE

$\lambda_1 \times 10^3 \, (\text{ft.}^{-1})$
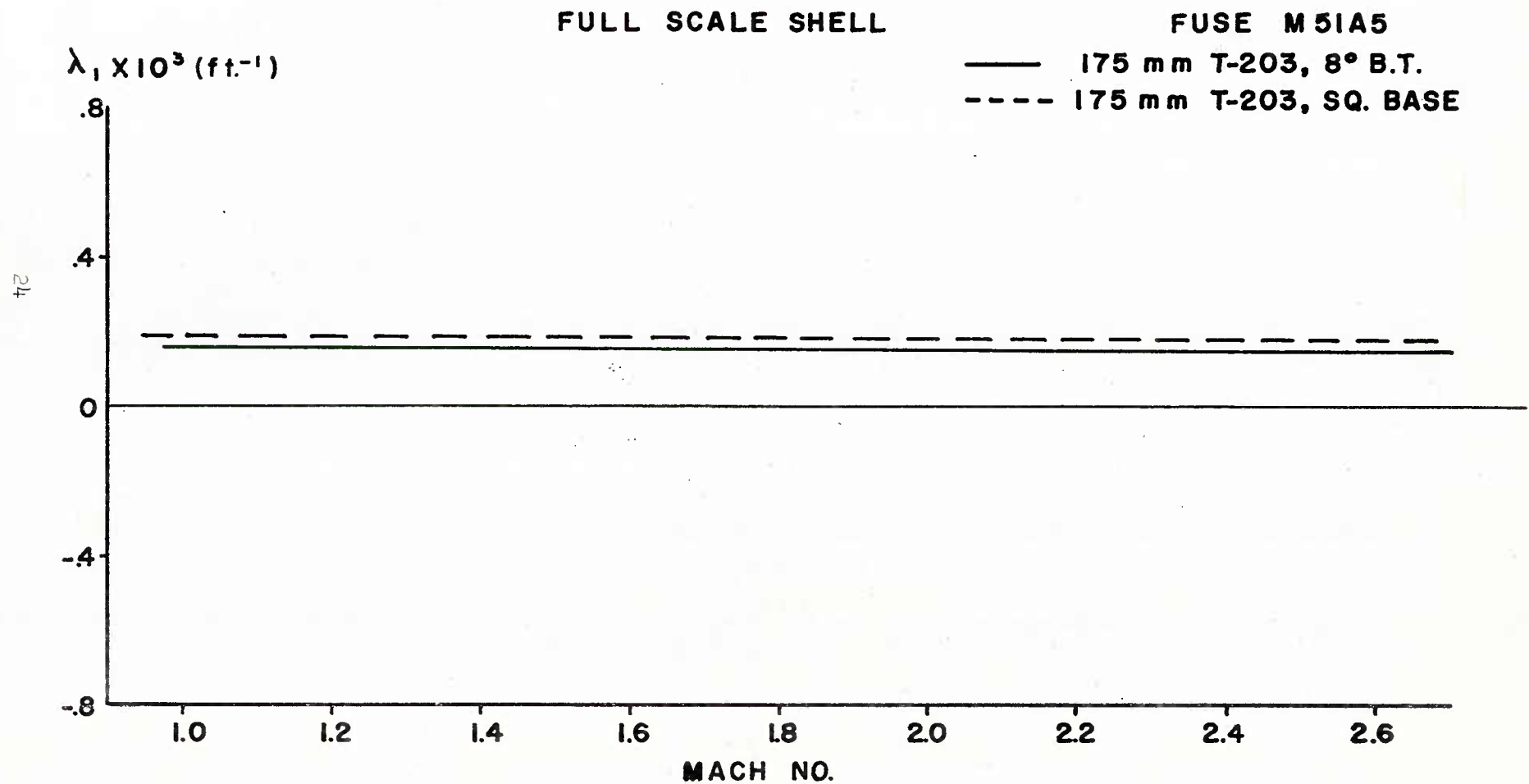
MACH NO.

FIG. 9

PRECESSIONAL YAW DAMPING RATE, $e^{-\lambda_2 z}$
VS.
MACH NUMBER

FULL SCALE SHELL   FUSE M5IA5

—— 175 mm T-203, 8° B.T.

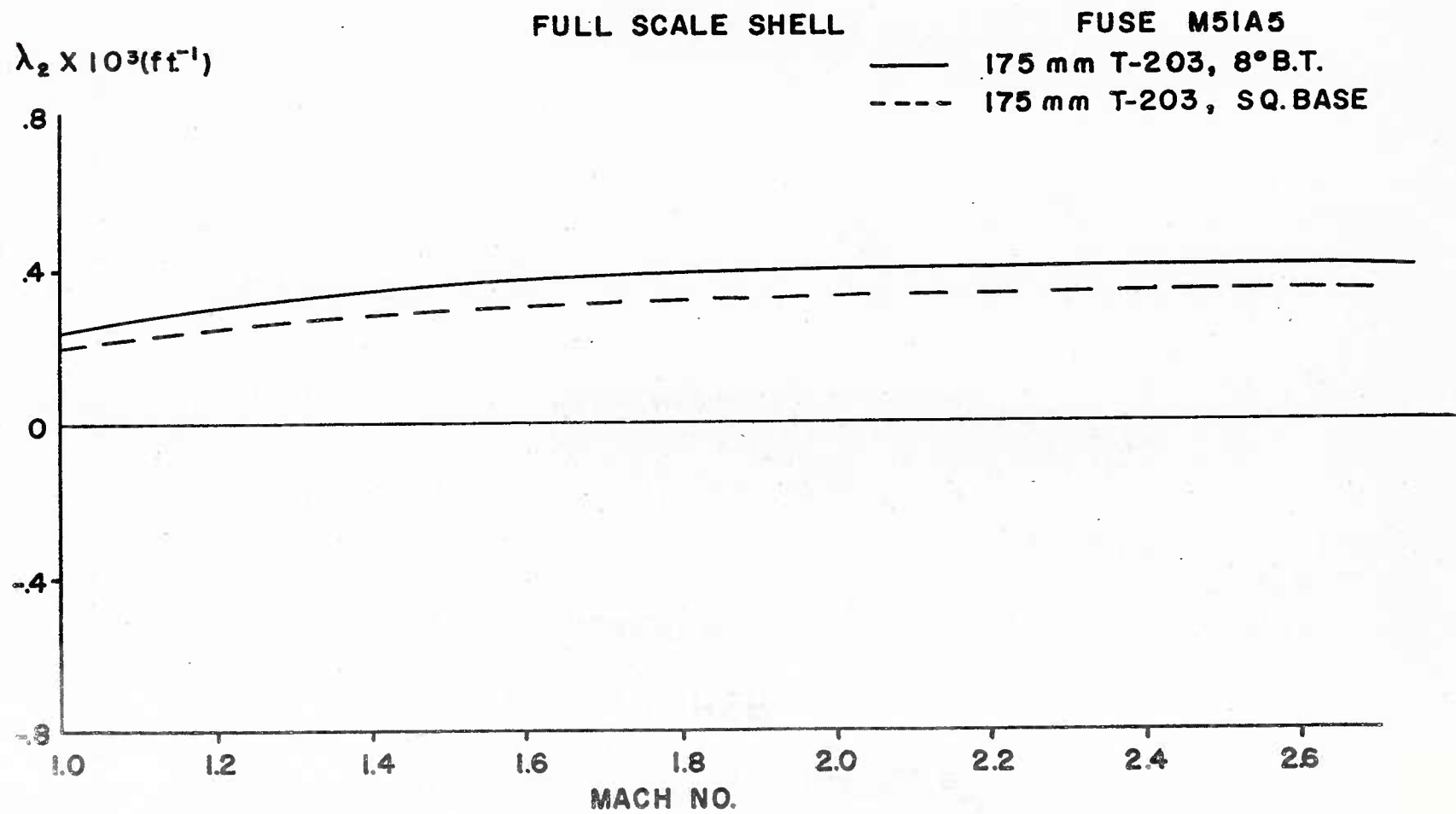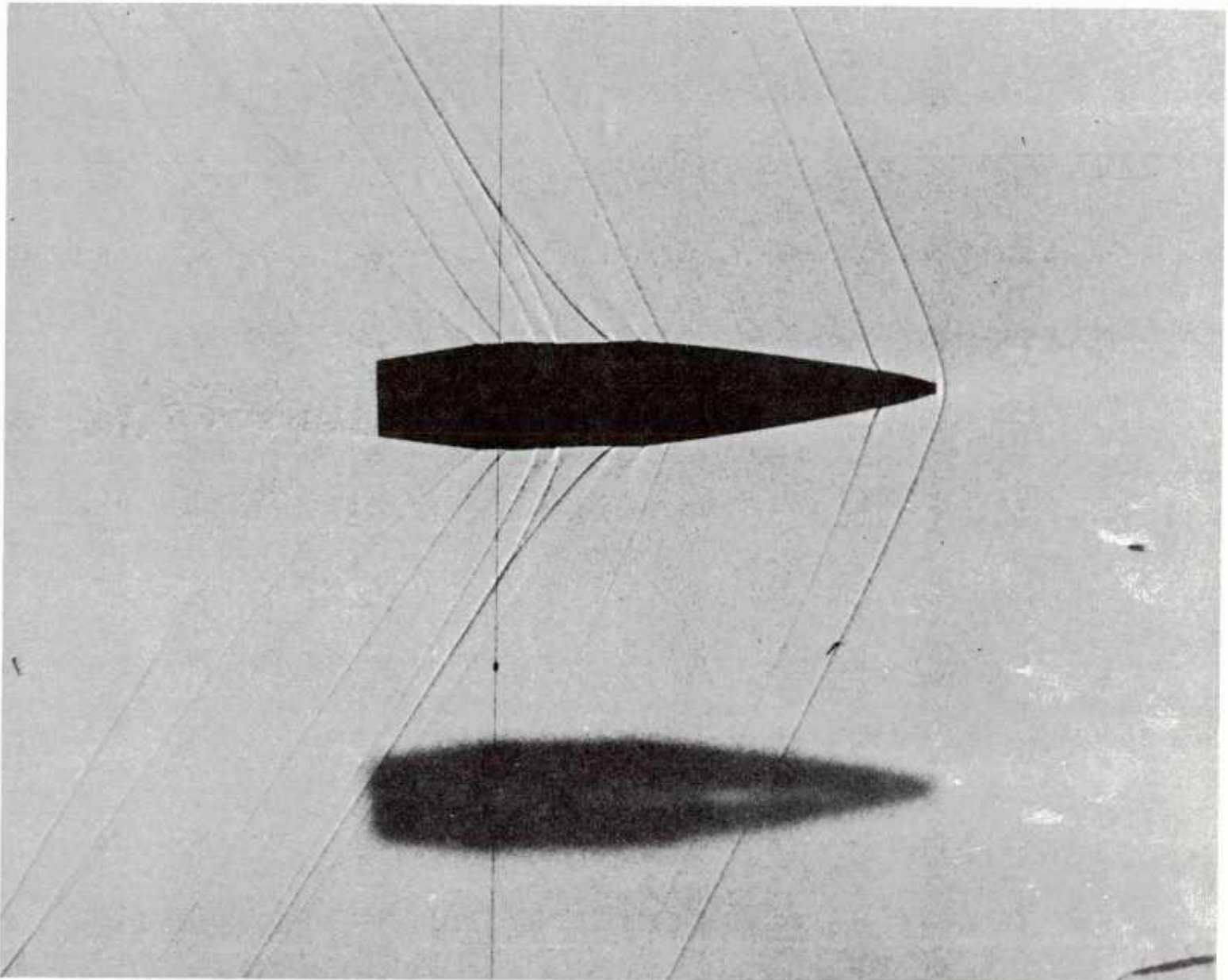- - - - 175 mm T-203, SQ. BASE

FIG. 10

FIG. 11. Shadowgraph of a 90MM model of an 8° B.T. 175MM shell, M = 1.14.

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FIG. 12. Shadowgraph of a 90MM model of a square base 175MM shell, M = 1.20.
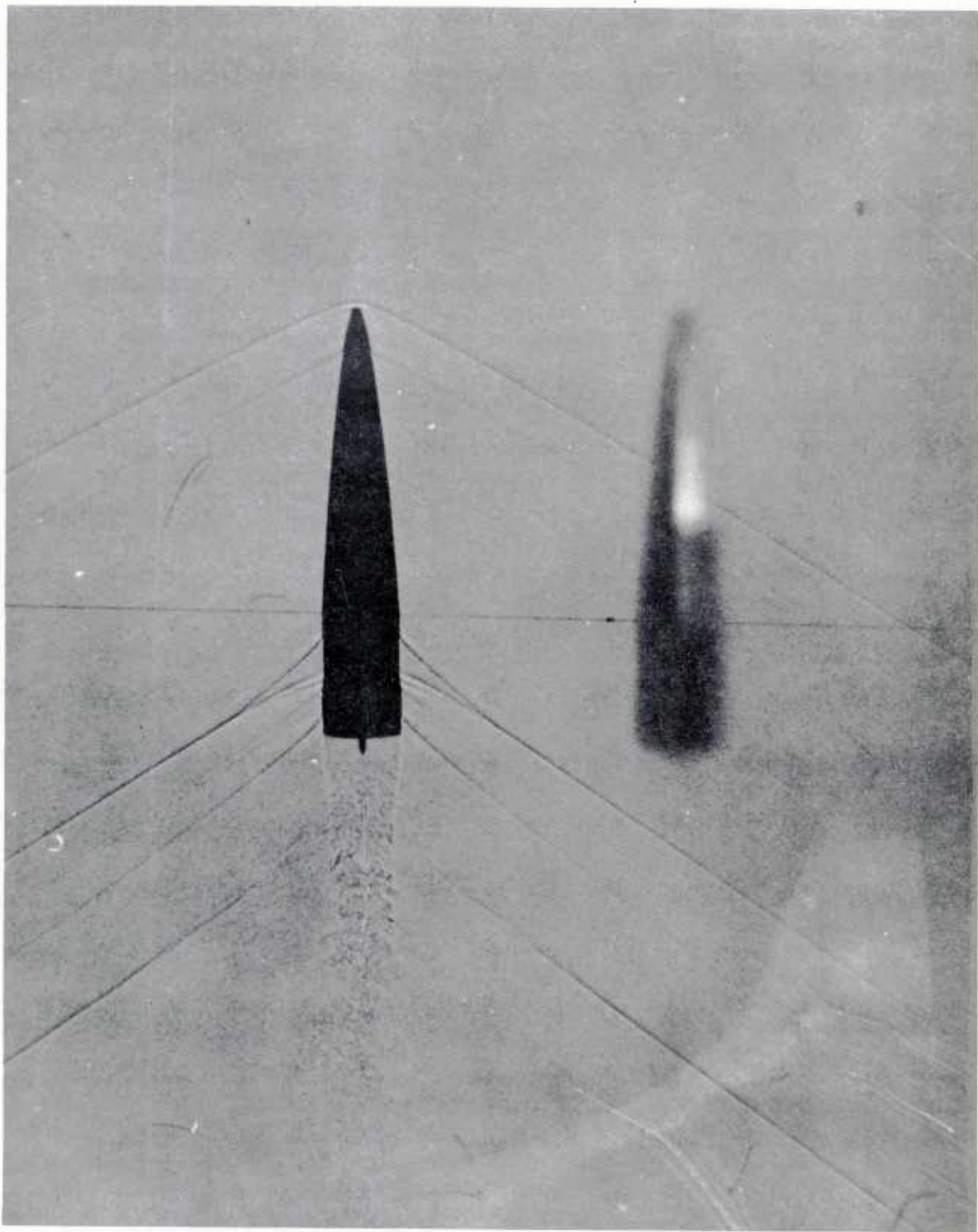
FIG. 12. Shadowgraph of a 90MM model of a square base 175MM shell, M = 1.20.

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FIG. 13. Photograph of an M3, 90MM gun.

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1. Rogers, W.K., *The Transonic Free Flight Range*, BRL Report 849 (1953).

2. Murphy, C.H., *Data Reduction for the Free Flight Ranges*, BRL Report 900 (1954).

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1	Firestone Tire and Rubber Co. Defense Research Division Akron 17, Ohio Attn: Mr. G. L. March